#7599 IMPACT OF SENSOR-BASED PRECISION NITROGEN MANAGEMENT ON WHEAT YIELD AND NITROGEN USE EFFICIENCY

Abdou A. Soaud[1], A. El-Metwally[2], M. Ali[3] and Radwa K. Sayed[1]
[1]Department of Soil Science, Faculty of Agriculture, Cairo University, Egypt. [2]Department of Agronomy, Faculty of Agriculture, Cairo University, Egypt. [3]Department of Soil Fertility and Microbiology, Desert Research Center, Egypt, a2soaud@yahoo.com

ABSTRACT

Optical sensors are promising new technology for precision nitrogen management in crops. Fertilizer N management for wheat (Cultivar: Giza 171) using optical sensor (GreenSeeker®) was evaluated at the Experimental Farm of Faculty of Agriculture, Cairo University, Giza Governorate, Egypt. The experiment was laid out in randomized block design with three replications during two successive winter seasons (2017/2018 and 2018/2019) to quantify the relationship between N uptake at jointing growth stage with GreenSeeker measurements and to formulate a strategy to optimize N fertilizer use efficiency. An increasing rate of N fertilizer was applied in the experiment conducted in the first season to create variability in GreenSeeker readings (Normalized Difference Vegetation Index, NDVI) determined at jointing growth stage of wheat. The data revealed that relationship between total N uptake and sufficiency index (SI, SI=VDVI of the measured treatment/NDVI of the reference treatment)) of NDVI measured by GreenSeeker at Feekes 6 growth stage of wheat fitted to power function ($y= 291.47x^{-1.686}$). The suggested exponential model based on the GreenSeeker could explain about 78% of the variation in N uptake. Accordingly, a strategy to refine N application dose applied at jointing growth stage of wheat was suggested as guided by the sensor in the second season. The suggested strategy was applying 0, 10, 61, 77, 85 or 109 kg N ha^{-1} corresponding to sufficiency index of NDVI values of 0.80, 0.74, 0.72, 071 and 0.68, respectively. When appropriate prescriptive N fertilizer was applied (100 kg N ha^{-1}in two splits, 40 and 60 kg N ha^{-1}) followed by corrective dose (161 kg N ha^{-1}) as guided by the GreenSeeker, the achieved N recovery efficiency was 74.1% compared with 51.5% in the general recommendation. The grain yield of this treatment has no statistically significant effect compared with general recommendation treatment. This study indicated that N fertilizer could be managed more efficiently in wheat using GreenSeeker sensor compared with the current general recommendation.

Keywords: nitrogen use efficiency, GreenSeeker, sufficiency index, NDVI, wheat

MATERIALS AND METHODS

The Experimental Site

In two successive winter seasons (2017/2018 and 2018/2019), field experiments were carried out on wheat (Triticum aestivum L.) variety Giza 171 at the Experimental Farm of the Faculty of Agriculture, Cairo University, Giza Governorate , Egypt. Initial soil samples were taken from the experimental site and analyzed using the procedures outlined by Page et al. (1982) for physical and chemical characteristics as recorded in Table 1.

Table 1. Some physical and chemical properties of the topsoil (0-30 cm) of the experimental site.

Texture	pH*	EC** dS m^{-1}	Organic matter %	Available N mg kg^{-1}	Available P mg kg^{-1}	Available K mg kg^{-1}
Clay Loam	7.91	4.53	2.30	100.90	18.50	354.00

* pH in saturated soil paste.
** Electrical conductivity in saturated soil paste extract.

Experimental Design and Treatments

The soil has been ploughed and levelled prior to sowing. In both seasons, in mid-November, wheat (Triticum aestivum L.) of the variety Giza 171 grains was mechanically sown in rows 15 cm apart and divided into 15 m^2 parcels. N fertilizer levels of 0, 40, 80, 120, 160, 200, 240, 280 and 320 kg N ha^{-1} were added in three equal split doses in the first season as ammonium sulphate. This range was used to determine plots with great variability in the wheat uptake and yield of N. The second season was developed to validate the effectiveness of the GreenSeeker Sensor for the application of N fine-tuning fertilizer. The treatment consisted of setting various prescriptive N application scenarios at the early growth stage, followed by a corrective dose at the joint growth stage, as directed by GreenSeeker. The experiments were performed with three replications in a randomized complete block design. Following the general recommendation, phosphorus (as a single superphosphate) was applied for sowing. Potassium fertilizer was avoided because sufficient quantities of available K (354 mg kg^{-1}) were present in the soil.

Plant Sampling and Analysis

At the joint growth stage, over ground plant samples from an area of 1 m^2 were collected from each plot straight after the GreenSeeker readings were obtained. The wheat production was manually collected from a net area of 6 m^2 at maturity from the centre of each plot. Grain and straw samples are collected from each plot were left to dry to constant weight and soil in the hot air oven at 70°C. Samples were digested in a mixture of H_2SO_4-H_2O_2, and total N was determined using the micro-Kjeldahl method (Kalra, 1997).

Calculations and Statistical Analysis

Using Microsoft excel program (a component in Microsoft Office 2016), regression models were mounted. Variance analysis (ANOVA) has been used to evaluate the effect of N treatments on the data collected. As described by Gomez and Gomez (1984), Duncan's multiple range test (DMRT) at probability value < 0.05 was used to examine the difference between means. As described by Cassman et al. (1998), the recovery efficiency of N (RE_N) was computed as:

$$RE_N(\%) = \frac{Total\ N\ uptake\ in\ fertilized\ plot - Total\ N\ uptake\ in\ zero\ N\ plot}{Quantity\ of\ applied\ N\ fertilizer}$$

RESULTS AND DISCUSSION

Effect of N Fertilizer Application Rate on Grain Yield of Wheat

In contrast to the increasing N fertilizer rate, grain yields of wheat collected from the first season study were plotted (Fig.1). The relationship exhibited a second-degree response function, as is shown in the curve. Function derivation analysis show that the highest grain yield of 8881 kg ha^{-1} can be achieved by applying an N fertilizer rate of 215.8 kg N ha^{-1}.

Approximately 155 kg N ha^{-1} was calculated as the N fertilizer rate required for economic grain yield (8437 kg ha^{-1}, 95 percent of maximum yield). The widely adopted general N fertilizer recommendation for wheat in the area is 180-240 kg N ha^{-1}. In addition, N fertilizer levels are usually applied by farmers even higher than the general recommendation, which means that unnecessary amounts of N fertilizer are applied. In addition to the susceptibility to loss of excess N fertilizer from the soil-plant system, it could also lead to soil health deterioration (Bijay-Singh, 2018). These results suggest that there is a need to establish site-specific management strategies in the season that have the ability to adjust the rate of application of N fertilizer according to the actual need for the crop.

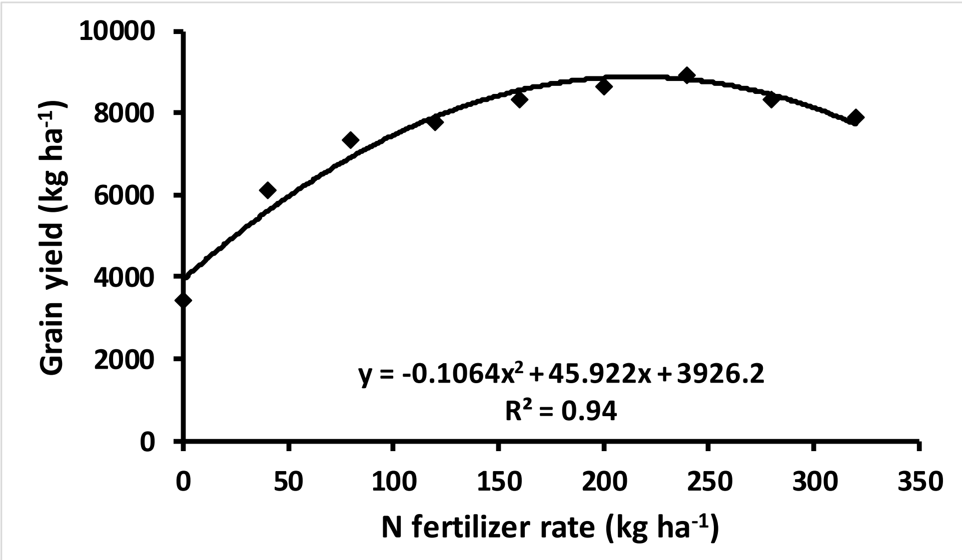


Figure 1. Response of wheat to increasing rate of N fertilizer fitted to quadratic function.

Prediction of N Uptake at Jointing Growth Stage using GreenSeeker

Rapid acquisition of N uptake information where plants can respond to N inputs prior to harvesting is essential for the development of a successful N fertilizer management plan for precision. Variation in N uptake at the joint growth stage of wheat was created by the increasing rate of N fertilizer applicable in the first season experiment. This variability has been reflected in grain yield increases. This data was derived from the relationship among grain yield and N wheat uptake:

Estimated maximum uptake = 373 kg N ha^{-1}
Estimated maximum yield = 7981 kg grain ha^{-1}
95% of the maximum grain yield = 7582 kg grain ha^{-1}
Optimum N uptake = 275 kg N ha^{-1}

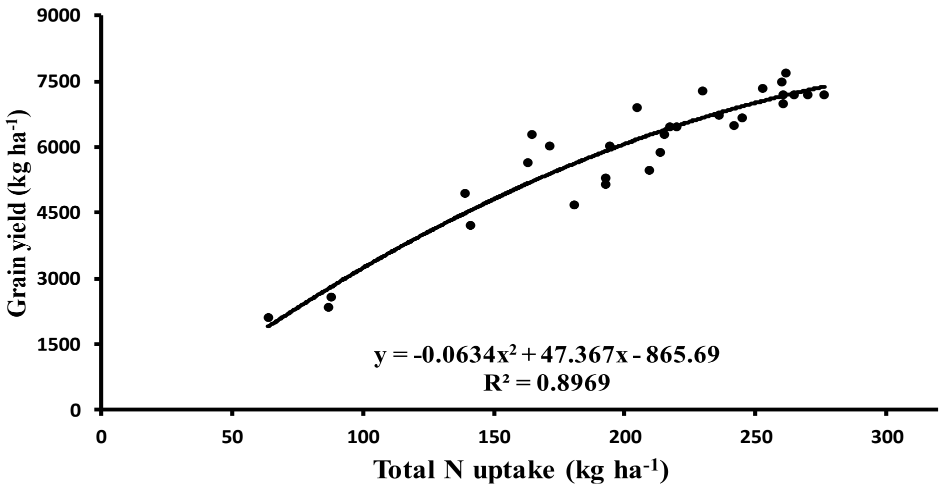


Figure 2. Relationship between grain yield and N uptake in wheat.

For the development of strategies to optimize N fertilization and reduce the environmental dangers associated with the application of high amounts of N fertilizer, monitoring of N uptake during the season is crucial. Inaccurate N uptake prediction may result in N fertilizer over- or under-applications as compared to the actual demands (Yao et al., 2012). Many other studies have also shown that in-season spectral measurements of leaf can estimate the N status and grain production of many crops (Varvel, 1997; Raun et al., 2001; Ali et al., 2014). In fact, portable hand - held sensors such as GreenSeeker have opened a new approach to quickly make precise choices in the season.

Sufficiency Index Approach for Managing N Fertilizer using GreenSeeker

By many varietal groups, seasons or regions, leaves greenness may vary. Consequently, one GreenSeeker fixed threshold value may not work effectively. The strategy to the sufficiency index (calculated as the ratio of NDVI reading of the evaluated plot and that of a reference N-rich plot) allows dynamic values instead of a fixed threshold value to be used for precision N management. According the variability of soil properties and seasons, this strategy has the potential to be self-calibrating.

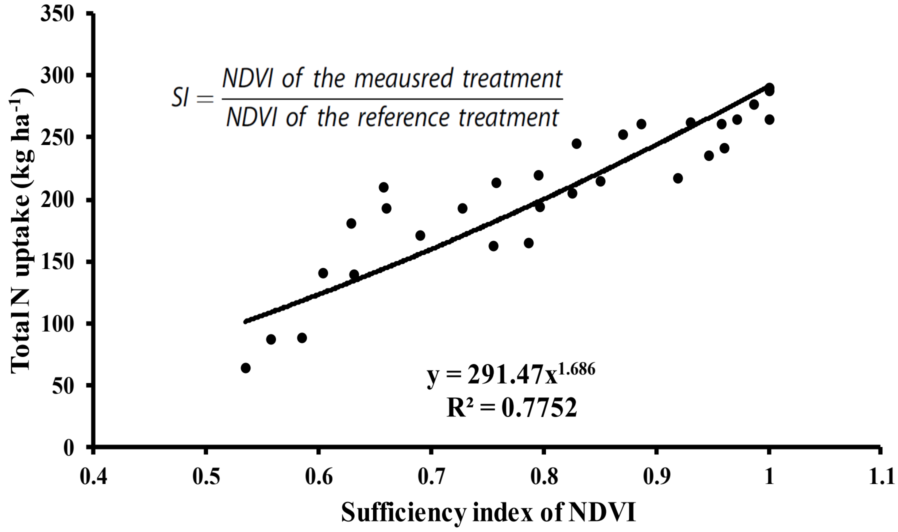
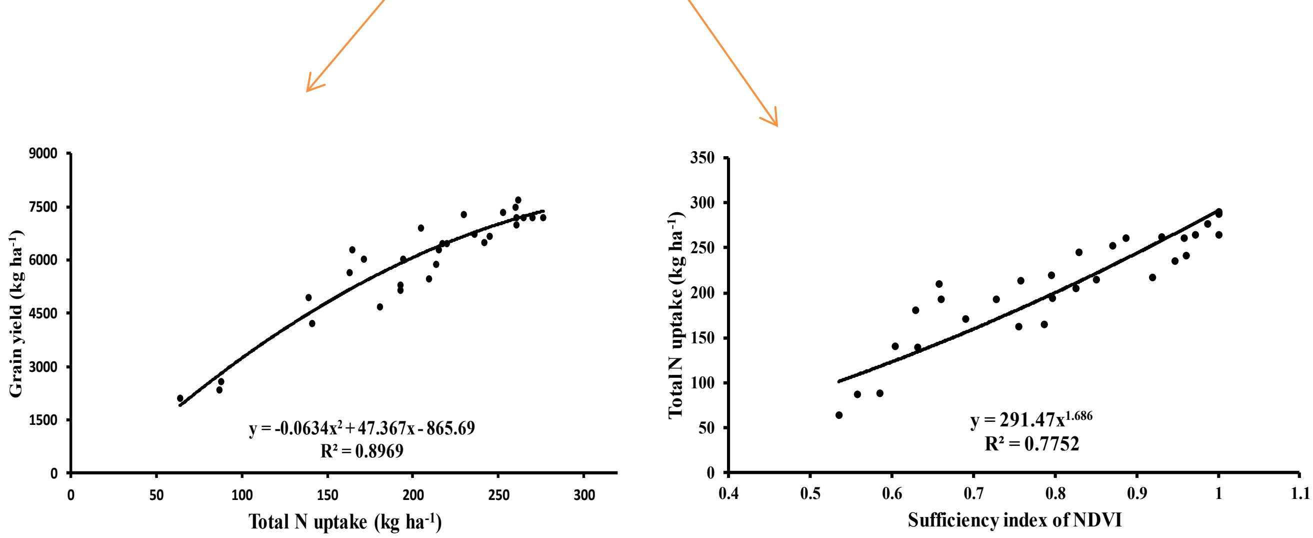


Figure 3. Relationship between total N uptake and sufficiency index of NDVI measured by GreenSeeker at Feekes 6 growth stage of wheat fitted to power function.

In keeping with these findings, it was recommended a strategy to modify N application dose be added in the second season at jointing stage of wheat, as steered by the GreenSeeker. From this algorithm N fertilizer dose (kg N ha^{-1}) was calculated as:

The proposed algorithm

$$\textbf{N fertilizer dose (kg N ha}^{-1}\textbf{)} = \frac{275 - 291.47 \times SI\ NDVI^{1.686}}{0.65}$$



In this study, the GreenSeeker values at jointing wheat growth stage matched Feekes 6 growth stage (approximately 50 days after sowing) and this is considered to be the suitable stage for obtaining information and making decisions on in-season N fertilizer management. For example, Raun et al. (2001) found that the relationship between both the readings of optical sensors and wheat grain yield was the highest among Feekes 4 and 6 stages. Zhang et al. (2019) also noted that leaf dry matter in wheat is more varied than other stages during Feekes stages 4 to 7, and that agricultural information can be obtained accurately.

Validation of GreenSeeker in Managing N Fertilizer

The experiment performed during the second season has been used to assess the GreenSeeker sensor performance as proposed in this study. Various doses and timings of N fertilizer were added prior to applying the corrective dose as steered by the GreenSeeker to make growth variance in biomass and N uptake in wheat.

The data mentioned in table (2) show that the grain yield was obtained in Treatment # 3 (applying 40 and 60 kg N ha^{-1} at 0 and 30 DAS, respectively, followed by a corrective dose of 60.9 kg N ha^{-1} as guided by the GreenSeeker for a total of 160.9 kg N ha^{-1}) is approximately equal to the yield was obtained in the general recommendation, but with 79 kg N ha^{-1} less. Other treatments demonstrated the GreenSeeker's effectiveness in increasing or decreasing the N fertilizer levels at jointing growth stage, depending on the plant's need. The N management based on GreenSeeker successfully overcame the variability in wheat growth caused by various prescriptive N management and with less N fertilizer quantities had been used.

RE_N data indicate that GreenSeeker-guided N treatments have resulted in greater efficiency of use compared with the general recommendation. For example, when suitable prescriptive N fertilizer (Treatment # 3) was applied, accompanied by a corrective dose as guided by the GreenSeeker, a 22.6 percent increase in RE_N compared to the general recommendation. Therefore, by using GreenSeeker in guidance N management could efficiently control N fertilizer to achieve higher yield along with less N fertilizer being applied.

Table 2. Wheat grain yields, total N uptake, and N use efficiencies as influenced by different N fertilizer treatments as guided by GreenSeeker sensor.

Treatment	N fertilizer		NDVI	Corrective	Total	Grain	Total N	RE_N +
	At sowing	30 days age	Feekes 6	dose kg N ha^{-1}	amount of N fertilizer kg N ha^{-1}	yield kg ha^{-1}	uptake kg ha^{-1}	%
T1 (zero-N)	0	0	-	0	0	3118 d	109.6 c	-
T2 (gen. rec.)	80	80	0.75	80 (fixed)	240	8023 a	233.4 a	51.5 c
T3	40	60	0.74	60.9	160.9	7989 a	228.9 a	74.1 a
T4	100	0	0.72	77.3	177.3	7373 b	238.7 a	72.8 a
T5	0	100	0.71	85.3	185.3	7742 a	243.2 a	72.1 a
T6	0	0	0.68	109.1	109.1	6114 c	183.5 b	67.7 b
T7	100	100	0.80	10.1	210.1	7871 a	224.6 a	54.7 c

+ RE_N = Recovery efficiency of nitrogen fertilizer.
Means followed by the same letter within the same column are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT).

CONCLUSIONS

The GreenSeeker sensor is proved to be an effective tool to predict N uptake in wheat from data measured at jointing growth stage. This hand-held GreenSeeker sensor can be used reliably for the management of N fertilizer in wheat. Accordingly, the application of corrective doses of 0, 80, 60.9, 77.3, 85.3, 109.1 or 10.1 kg N ha^{-1} corresponding to the sensor values of GreenSeeker has suggested a strategy. Compared to the general recommendation, the suggested strategy used effectively in the management of N fertilizer led to an increasing in N recovery efficiency level of 22.6 percent with statistically similar yield.

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